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Ringkøbing-Skjern Energy Atlas for municipal energy planning

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ABSTRACT

Ringkøbing-Skjern is Denmark's largest municipality, located in the west part of Central Denmark Region. Its medium-term goal is to achieve 100 % self-sufficiency in renewable energy supply by 2020. To achieve this ambitious goal, future courses of action have been outlined in the municipality's energy strategy "Energy2020" and divided into five groups: increasing production from wind, bioenergy and other renewable energy sources, reducing heat demand in buildings and converting transportation sector to renewable energy. The analysis of technical, economic and environmental impacts of such a variety of technologies on the municipality's energy system requires highly detailed decision support system. For that purpose, GIS-based energy atlas has been developed for Ringkøbing-Skjern municipality. The data about energy supply and demand, transmission and distribution infrastructure, energy resources, societal and other energy data have been geographically referenced and combined with the tools built in ArcGIS software.

The data have been collected from various sources: freely accessible public databases, the municipality, district heating and electricity companies, Danish transmission system operator, etc. The focus in the energy atlas is put on the geographical level of details, such as locations of district heating pipes and wind turbines, but the objects have been described with technical parameters and historical values as well. The applicability of the energy atlas is elaborated in the present paper and it is concluded that it can be used for analysis of heat saving measures in the building stock, district heating expansion and site-selection analysis for new wind turbines or biogas plants. In addition to that, it has proven to be useful as a data container and pre-analysis tool for energy system models and as a visualization tool. The continuous updating of the atlas while maintaining the sufficient level of data confidentiality is considered crucial for its long-term value; the strategy for continuous updating is presented in a separate section. Finally, since the methods and procedures used to create the atlas are irrespective from administrative boundaries, neither obstacle is observed towards creating the GIS-based energy atlases for other Danish municipalities or for Denmark as a whole.

KEYWORDS

GIS energy atlas, renewable energy system, energy system planning, energy conservation, energy efficiency, energy resources, supply and demand

INTRODUCTION

At the national level, Denmark is heading towards renewable energy future – at least 50 % of electricity consumption needs to be produced from wind power starting from 2020,

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production of electricity and heat needs to be renewable starting from 2035 while entire society needs to be 100 % renewable starting from 2050 [1, 2]. Lower administrative units, such as regions and municipalities are free to choose how to reach these goals.

Ringkøbing-Skjern, Denmark's largest municipality, located in the west part of Central Denmark Region has a goal of achieving 100 % self-sufficiency in renewable energy supply by 2020. The municipality's energy strategy "Energy 2020" outlined five fields in which progress should be made: energy production from wind, bioenergy and other renewables should be increased, heat demand in buildings should be reduced while transportation sector should be fuelled from renewable energy [3]. Geographical data are essential in describing each of these fields. For example, wind power is different from one location to another, bioenergy resources are greater in forests and agricultural areas than in city areas, wind turbines can't be installed close to residential buildings, competitiveness of heat saving measures depends on the position relative to existing district heating and natural gas grids, etc. To be able to take "geographical dimension" of municipality's energy transition into account Ringkøbing-Skjern Energy Atlas is developed. In addition to usual energy planning analysis, it has the ability to store, analyse and visualize spatial data, i.e. take into account where are the producers and consumers of energy, where are the resources, where is transmission and distribution infrastructure, etc.

Short summary of Danish spatial energy planning is based on [4]. Denmark has a rich history of spatial energy planning at a municipal level starting from 1973. Before that time energy planning was not performed. In 1973, Danish energy consumption was based on imported fuels - 93% on oil and 7% on coal. The First Oil Crisis revealed the vulnerability of the Danish energy sector to oil prices, negatively affected the Danish economy and declared the start of energy planning. At the national level, first major policy statement was published in 1976 and stated the following goals for the Danish energy sector: rapid reduction of dependency on oil, slower growth of energy consumption and creation of stable long-term solutions for energy supply. The following measures were prescribed to achieve these goals: insulation of buildings, increased utilization of district heating based on combined heat and power production and increased use of natural gas, coal and renewables. Relevant for the regional level, the Heat Supply Act was passed in 1979 with the aim to encourage the most economic use of energy for space heating and domestic hot water, and to reduce the dependency on oil. The law required from municipalities to map present and future energy needs at the local level on the basis of small heat districts and to make a plan for future heat supply. The plan contained type of future heating supply (district heating, natural gas or individual heating options), future location of investment in collective heating and location of specific activities producing or consuming large quantities of heat. In case of district heating, the municipality could specify the type of fuel to be used and thus influence the economic and environmental factors. The delineation of designated heat supply areas as well as mapping of heat supply are related to building stock and have a geographical dimension in it. Despite being performed on paper maps, before the progress of computer hardware and GIS software, these paper maps can be seen as first versions of local heat atlases.

Heat atlases proved to be useful for national-level energy planning in Denmark, mainly for analysis of heat savings in building stock and expansion of district heating systems. In [5] Danish heat atlas was used as input to a model which calculates potentials and costs of heat saving measures in the residential building stock. Danish heat atlas was used by Zvingilaitė [6] to provide information about location, heat sources and heat demands in buildings. Later, optimal level of heat savings and environmental benefits are analysed with an energy system

optimisation model of the Danish heat and power sector. In [7] heat atlas was used to group buildings according to building type, primary and secondary heating and construction period before calculating the optimal heat supply costs from private-economic perspective while accounting for health impacts. Locations of buildings, their type and construction period were extracted from heat atlas in [8] prior to analysing the role of heat savings in 100% renewable heat and power system with different shares of district heating. Sperling and Möller have used the heat atlas in [9] together with an energy system model to evaluate expansion of district heating and implementation end-use energy savings in existing and renewable local energy system of Frederikshavn. The methodology for calculating potentials and costs of heat saving measures and district heating expansion by utilising heat atlas was presented in [10]. The heat atlas was used in [11, 12] to calculate costs of district heating expansion and input them to energy system models to discover the interaction of district heating with the energy system. Nielsen and Möller have used the heat atlas in [13] to quantify heat demand and the number of buildings located within district heating areas and to find historical development of single-family houses before using EnergyPRO software for techno-economic analyses. The heat demand and heated area were extracted from heat atlas and fed into a GIS model for assessing district heating potentials and costs [14, 15].

The Danish heat atlas is based on the BBR¹ register which provides the data about building stock and is mainly used for analysis of heat savings in building stock and district heating expansion. Ringkøbing-Skjern Energy Atlas is an extension of heat atlases at the municipal level. It contains more details about district heating and building stock, such as productions of district heating plants, amounts of district heat delivered to buildings, amounts natural gas delivered at local measuring stations, etc. In addition to that, Ringkøbing-Skjern Energy Atlas also includes transmission and distribution infrastructure, energy resources, power production facilities and various energy related data.

RINGKØBING-SKJERN ENERGY ATLAS

Ringkøbing-Skjern Energy Atlas is a GIS-based tool for energy planning and analysis in Ringkøbing-Skjern municipality. It is composed of the GIS database and tools built in ArcGIS 10.1 software, as presented in Figure 1. The database is characterized by high level of geographical and non-geographical details. For example, in addition to spatial coordinates, buildings are characterized by heated area, construction year, heating source, etc.; positions of wind turbines, district heating plants and heat storages are supplemented with their technical characteristics and historical data.

¹ BBR is an acronym for Danish register of buildings and dwellings.

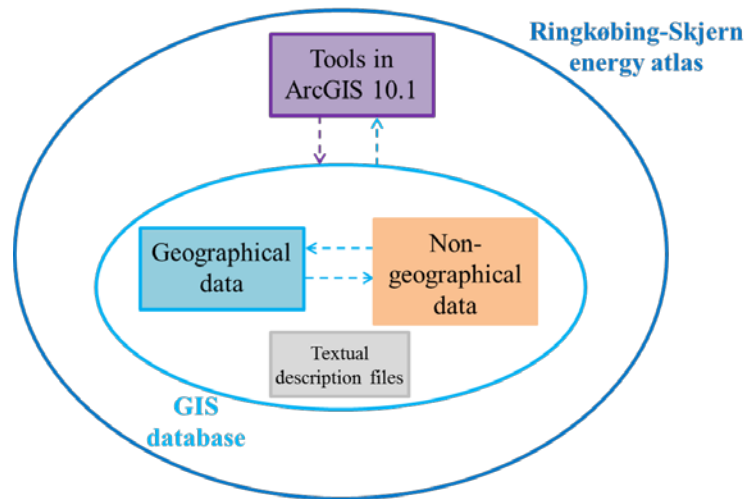


Figure 1. Graphical illustration of Ringkøbing-Skjern Energy Atlas

For users without major knowledge of GIS tools, Ringkøbing-Skjern Energy Atlas is intended to be used as a data-container and a visualization tool. Good connectivity, functionality in working with databases and user-friendly interface of ArcGIS software 10.1 enable storage of large datasets and production of illustrative maps. Additionally, advanced GIS users can query or edit the database, perform GIS analysis and spatially represent results. As an example, three analysis which can be done using Ringkøbing-Skjern Energy Atlas are presented in following sections: calculation of investment costs of expanding district heating network, providing inputs to calculation of potentials and costs of heat saving measures and finding location for installation of wind turbines.

Elements of Ringkøbing-Skjern Energy Atlas

Ringkøbing-Skjern Energy Atlas is composed of five main folders, representing five main thematic data groups: Energy resources, Transmission and distribution infrastructure, Supply and demand, Social data and Other energy data. Each of these folders is further divided into subfolders, as presented in Table 1. In some cases there are several levels of subfolders. Due to simplicity, not all levels of subfolders are presented in Table 1.

The subfolders contain useful data and a single Description file. The useful data are usually GIS files, but can also be Excel spreadsheets. Description files are textual files which describe contents of folders, declare whether the data are public and provide a reference (in case the data are public) or contact details of a person who provided the data (in case the data are not public). A snapshot of a textual Description file is presented in Figure 2.

Table 1. Contents of Ringkøbing-Skjern Energy Atlas

Folder	Subfolder	Content
Energy resources	Manure potential	Positions of farms and annual manure production
	Recycling facilities	Positions, sizes and types of recycling facilities
	Solar resource	Hourly values of available solar heat at 6 measuring points
	Wind resource	Average wind speed, wind power density and Weibull parameters at four different heights in raster cells of 200 x 200 m
Transmission and distribution infrastructure	District heating	Position of distribution infrastructure, heat storages and solar heating plants and historical values about delivered heat to each building
	Natural gas and biogas	Locations of transmission and distribution pipelines, measuring stations and planned biogas pipeline and historical consumption at measuring stations
	Electrical	Positions of transmission and distribution overhead lines, cables and transformers and historical consumption at transformer stations
Supply and demand	BBR data	Positions and detailed data about building stock (areas, construction year, use, etc.)
	Energy supply areas	Position of electricity supply areas divided by distribution company and heat supply areas divided by type of heating
	Hydrogen stations	Positions and ownership of hydrogen charging stations
	Planned biogas plants	Positions of planned biogas plants
	Production facilities	Positions, technical characteristics and historical values of district heating, solar heating plants and wind turbines
Social data	Population count	Population count in each town and village
	Property values	Sum of values of buildings and ground in raster cells of 100 x 100 m
Other energy data	Ground parcels	Positions of all cadastral parcels
	Roads and railways	Positions of roads and railways and measured number of vehicles on roads
	Soil types	Positions of different soil types
	Detailed topographic map	Boundaries of towns, villages and buildings, positions of natural areas, water bodies, technical facilities, height above sea, etc.

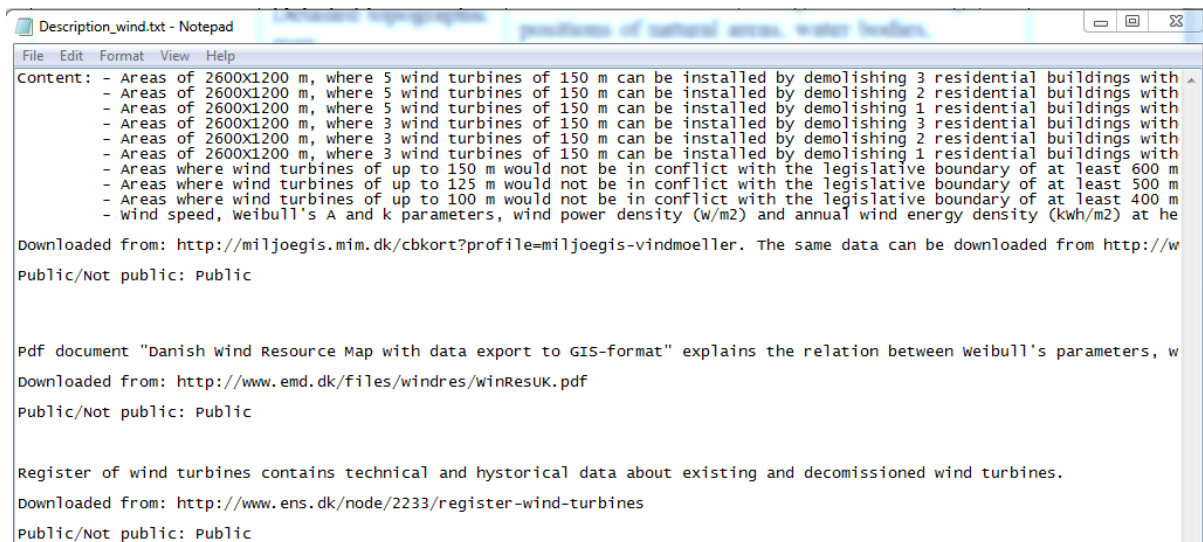


Figure 2. Textual file describing publically available data

Data sources and ownership.

Data in Ringkøbing-Skjern Energy Atlas belong to different thematic groups, as presented in Table 1. These data are gathered from different sources. Some of the data are obtained from public sources, some from Ringkøbing-Sjern municipality, while some are obtained from private and public companies. Consequently, data have been divided into 3 groups according to ownership:

1. Public data
2. Data owned by Ringkøbing-Skjern municipality
3. Non-public data

Public data can freely be used and updated from the location specified in a textual Description file. Data owned by Ringkøbing-Skjern municipality and non-public data are obtained under a condition that they will be used only for research and that results derived from these data will be published only on aggregated level. For other purposes than research, such as commercial projects, person who provided should be contacted and asked for permission to use the data. This person is named in a textual Description file, along with his/hers contact details. Data provided by Ringkøbing-Skjern municipality are put in a separate group for two reasons. First, employees in the municipality are allowed to use these data without further permission and can update these data internally within the municipality. Second, the municipality is the largest individual provider so it is convenient for users not working for the municipality to update or get permission to use these data with a single contact.

Updating of Ringkøbing-Skjern Energy Atlas

In order to maintain its practical value, Ringkøbing-Skjern Energy Atlas needs to be regularly updated. Thematically, it contains various types of data. Some data are likely to be different from one year to another, such as natural gas consumption at a certain measuring station or electricity consumption at a certain transformer station. On the other hand, stock of installed wind turbines changes few years, while solar resource, population count or transportation network are unlikely to be changed in a long time. As a result, it is not necessary to update all data in the energy atlas every year.

To facilitate the update process, Update list is created. For all data in the atlas, Update list specifies:

- Location – folder and subfolder.
- Type of data – geographical data or numerical data.
- Preferred interval between updates – less than 1 year, 1-5 years and more than 5 years.

Part of the Update list which refers to Transmission and distribution infrastructure is shown in Figure 3. Geographical data in Figure 3 are referring to geographical location of certain elements, such as district heating pipes or power transformers; numerical data, such as delivered district heat to buildings or electricity demand at transformer stations are describing the geographical data.

Nr.	Folder	Subfolder	Type of data	Preferred period between updates
1.1	Transmission and distribution infrastructure	District heating	Geographical data	more than 5 years
			Numerical values	1 year
1.2		Electrical	Geographical data	more than 5 years
			Numerical values	1 year
1.3		Natural gas and biogas	Geographical data	1-5 years
			Numerical values	1 year

Figure 3. A part of the Update list referring to Transmission and distribution infrastructure

When update of a certain folder or the whole energy atlas is to be undertaken, data providers need to be contacted. These persons are named in the textual Description files along with contact details. However, it can be time-consuming to open one textual Description file after another in order to find the contact details. To avoid this, Contact list is created. It contains contact details of persons which provided the data, along with their positions and fields of expertise. A part of the Contact list is presented in Figure 4. This list contains only persons which have actively contributed by providing data; persons which have not responded to requests for data or have responded negatively are not listed. Besides updating, Contact list is supposed to be used when expanding or editing the atlas or asking data owners for permission to use some of the contained data.

Nr.	Name	Lastname	Position	Telephone 1	Telephone 2	Mail	Field 1	Field 2
1	Thomas	Thomsen	Head of Secretariat for Renewable Energy at Ringkøbing-Skjern municipality	Direct: 46 74 88 11	Mobile: 23 25 30 00	thomas.thomsen@rsk.dk	General expert	
2	Jesper	Thomsen	Director at Ringkøbing Fjernvarmeværk	Direct: 46 74 88 11		jesper@rfv.dk	District heating	GIS
3	Thomas	Thomsen	Energy analyst at Energinet.dk		Mobile: 23 25 30 00	tom@energinet.dk	Electricity transmission	Natural gas transmission
4	Thomas	Thomsen	President at Trolldhede Kraftvarmeværk	Direct: 46 74 88 11		tom@tmail.com	District heating	GIS
5	Thomas	Thomsen	Legal consultant for Process engineering and measurement at Energinet.dk	Direct: 46 74 88 11		tom@energinet.dk	Natural gas transmission	GIS

Figure 4. A part of the Contact list

APPLICATIONS OF RINGKØBING-SKJERN ENERGY ATLAS

ArcMap 10.1 is integral part of Ringkøbing-Skjern Energy Atlas. As a result of that, Ringkøbing-Skjern Energy Atlas can be utilized for stand-alone analysis or as a pre-analysis tool for energy system models. Three applications of Ringkøbing-Skjern Energy Atlas will be presented in this section: calculation of investment costs of expanding district heating network, providing inputs to calculation of potentials and costs of heat saving measures and finding location for installation of wind turbines. In order to emphasize high level of geographical details and their influence, proposed procedures done from the municipal perspective are compared with the equivalent procedures done from the national perspective.

The aim of these analyses is to illustrate functionalities and data variety of the energy atlas. They can be performed even by users without extensive GIS knowledge. Advanced GIS users, experienced engineers or energy system modellers will be able to go further with the analysis and perform site selections, distance and network analyses, advanced raster calculations, spatial statistics, etc.

Investment costs of expanding district heating networks

The aim of this analysis is to show how Ringkøbing-Skjern Energy Atlas can be utilised to calculate investment costs of expanding existing district heating grid. As an example, investment costs of connecting individual heat consumers in the town of Højmark to existing district heating network in the town of Lem are calculated. Designated heat supply areas in Ringkøbing-Skjern municipality, including towns Højmark and Lem are presented in Figure 5. BBR dataset, positions of district heating network in Lem, municipal and private roads have been utilised in this analysis. BBR dataset contains data about building stock, such as location, construction year, area, building type, type of heat supply, etc. Every element in the BBR dataset corresponds to a single building and is presented as single point in the Ringkøbing-Skjern Energy Atlas.



Figure 5. Designated heat supply areas in Ringkøbing-Skjern municipality

The procedure is as follows:

1. Point features from the BBR dataset are projected on top of the base map. Buildings are grouped into three groups according to type of heat supply: Buildings supplied by district heating, individually heated buildings and buildings without heating installations.

2. Existing district heating network in Lem and municipal and private roads are added on top of the base map, as presented in Figure 6. It is assumed that the future district heating pipes will follow the roads, i.e. the total length of district heating pipes is assumed to be equal to the length of roads. The transmission pipe corresponds with municipal road connecting Lem and Højmark, while distribution pipes correspond to private roads within Højmark.

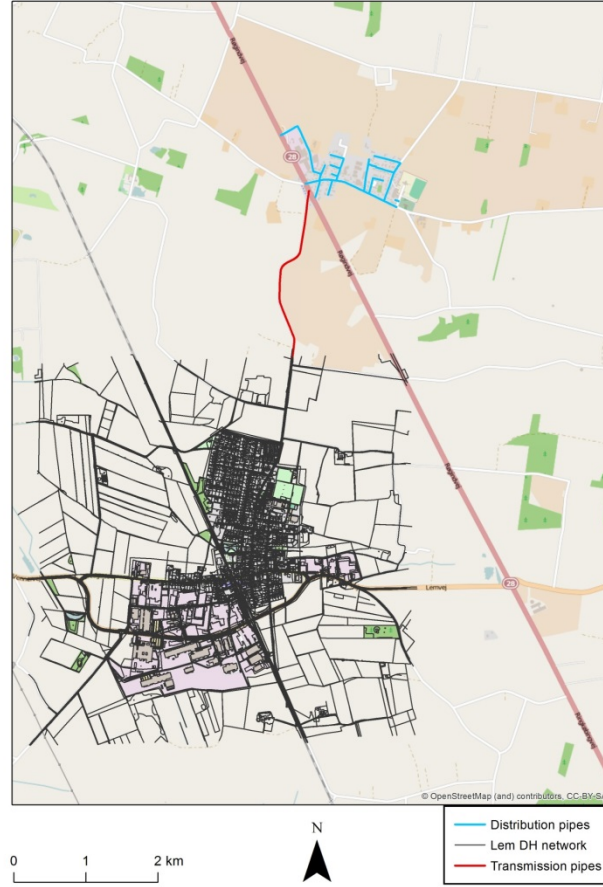


Figure 6. District heating network in Lem and assumed transmission and distribution district heating pipes

3. Buildings and roads in Højmark are presented in Figure 7. It is assumed that the number of heat exchangers and connecting pipes is the same as number of buildings. The price of heat exchangers and connecting pipes is assumed to depend on the area of buildings. The preference towards connecting to district heating is assumed to depend on use of buildings. For that reason, buildings are divided into three groups according to heated area ($< 200 \text{ m}^2$, $200\text{-}500 \text{ m}^2$ and $> 500\text{m}^2$) and five groups according to building use (Residential, Public, Service, Industry, Rest and recreation).
4. Total costs of connecting buildings in Højmark to district heating network in Lem are calculated as follows:

$$C = C_{TR} + C_{DIST} + C_{CONN} = c_{TR} \cdot l_{TR} + c_{DIST} \cdot l_{DIST} + \sum_{s=1}^3 n_s \cdot c_{CONN,s} \quad (1)$$

The used symbols have the following meaning:

C , C_{TR} , C_{DIST} , C_{CONN} – Total investment costs, investment costs of transmission, distribution and connection infrastructure, respectively.

C_{TR} , C_{DIST} – Specific costs of transmission and distribution pipes (in DKK²/km), respectively.

l_{TR} , l_{DIST} – Length of transmission and distribution pipes (in km), respectively.

n_s , $C_{CONN,s}$ – Number of buildings and specific costs of connecting pipes and heat exchangers for specific size of buildings (in DKK/building), respectively.

s – Area of buildings ($s=1$ correspond to buildings smaller than 200 m², $s=2$ to buildings with area between 200 and 500 m² and $s=3$ correspond to buildings greater than 500 m²).

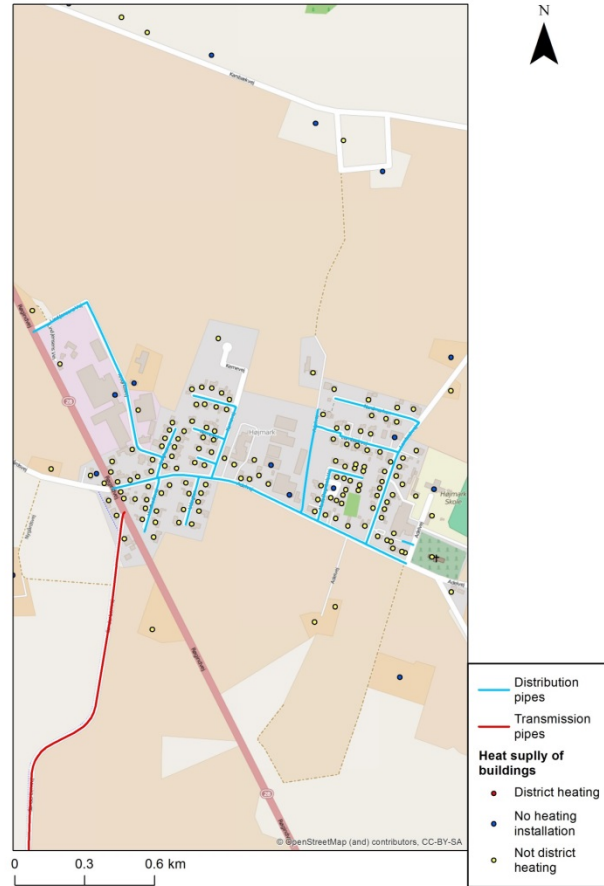


Figure 7. Buildings in Højmark and assumed transmission and distribution district heating pipes

BBR dataset used in step 1 and municipal and private roads used in step 2 are available at the national level. On the other hand, locations of the buried district heating pipes are locally known but are not available at the national level. Thus, the calculation of investment costs of district heating expansion summarized in Eq. 1 can't be performed using only the data available at the national level.

From the national perspective, calculation of investment costs of district heating expansion can be calculated according to methodology presented in [10]. BBR dataset available at the national level is sufficient for the analysis. From the national perspective, total costs of connecting buildings in Højmark to district heating network in Lem would be calculated as follows:

² DKK denotes Danish Crown throughout the paper. 1 DKK=0.134 EUR

$$C = C_{TR} + C_{DIST} + C_{CONN} = c_{TR} \cdot l_{DH-IND} + c_{DIST} \cdot A + \sum_{s=1}^3 n_s \cdot c_{CONN,s} \quad (2)$$

The used symbols have the following meaning:

l_{DH-IND} – Straight-line distance between centroid of Lem district heating area and centroid of Højmark.

c_{DIST} – Specific costs of district heating distribution infrastructure (in $\frac{\text{mill DKK}}{\text{km}^2}$).

A – Area of a Højmark in km^2 .

Other symbols were explained previously. The procedure for measuring distances and areas in ArcGIS 10.1 software is presented in Figure 8.

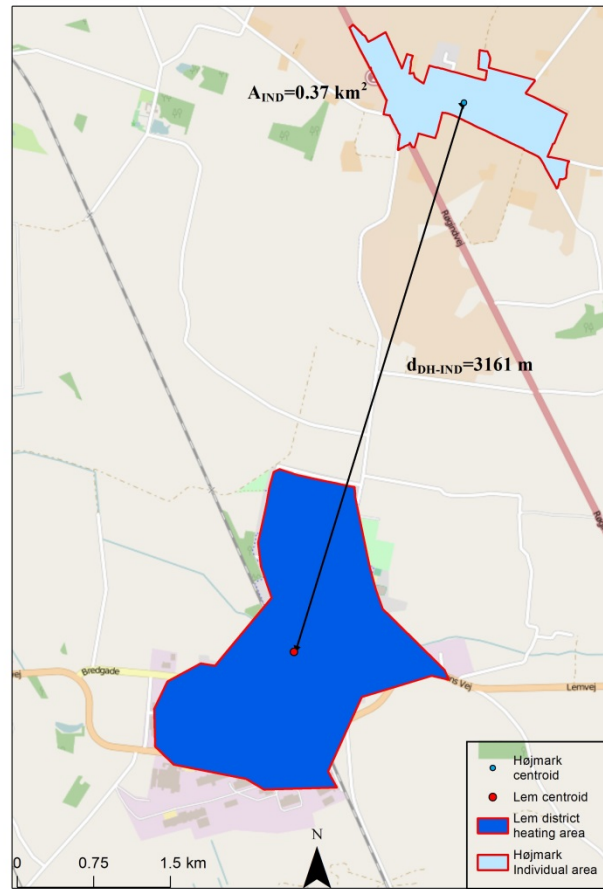


Figure 8. Calculation of investment costs of district heating expansion from the national perspective

Potentials and investment costs of heat saving measures

The aim of this analysis is to show how the Ringkøbing-Skjern Energy Atlas can be used to calculate potentials and costs of heat saving measures in residential building stock in Ringkøbing-Skjern. BBR dataset contained in the Ringkøbing-Skjern Energy Atlas, Heating Model developed at Energy Systems Analysis group at DTU, municipal energy statistics for 2013 [16], municipal temperature data [17] and municipal population count [18] are utilised in this analysis. BBR dataset is processed and used as input to Heating Model, while

municipal energy statistics, temperature data and population count are used for adjusting the model to the local conditions.

The residential buildings in Ringkøbing-Skjern are grouped into "building groups". A "building group" is group of buildings belonging to the same construction period, use and type of heating supply. This grouping by construction period and use is adopted from [19-21], while grouping according to the type of heat supply is adopted from the Danish energy statistics [22]. The total heated area in each "building group" is calculated and used as input to Heating Model. Other inputs to Heating Model include indoor temperature, ventilation and infiltration rates, internal heat gains, existence of ventilation systems with heat recovery, etc. The costs of heat saving measures are based on [19-21]. As a result, existing heating demand and potentials and costs of heat saving measures are automatically calculated for each "building group".

Heating Model was initially calibrated to match the delivered heat to each group of buildings (Single-family and Multi-family buildings) and each fuel expressed in the Danish energy statistics (oil, natural gas, district heating, renewable energy and electricity). When data about Ringkøbing-Skjern's residential building stock were inputted instead of national data, heating demand in the municipality turned out to be just 4.3 % lower than heating demand stated in municipal energy statistics, as presented in Figure 9. The calculated heat demand proved to be accurate in cases of district heating and natural gas and is deviating from the statistics in case of oil, biomass and electric heating.

Later, Heating Model was adjusted to local conditions – outdoor temperature, population count and municipal energy statistics. The population count is expressed in number of persons of different age classes living in different "building groups" and is essential for calculation of consumption of domestic hot water. The results of these adjustments are also presented in Figure 9. The resulting potentials and annuitized investment costs of heat saving measures before and after adjustment to local conditions are presented in Figure 10. The marginal costs represent costs of heat saving measures if they are done after the end of the lifetime of a specific component of building envelope (windows, roof, walls, etc.). Full costs represent costs of heat savings if they are done with the purpose of saving heat. The costs are annuitized with 4 % real discount rate over lifetimes of different elements of building envelope (20 years for ventilation systems, 25 years for windows, 35 years for roofs and 40 years for floors and walls). It can be concluded from Figure 10 that adjustment to local conditions does not make significant difference to potentials and costs of heat saving measures, i.e. national level analysis would provide accurate results for Ringkøbing-Skjern.

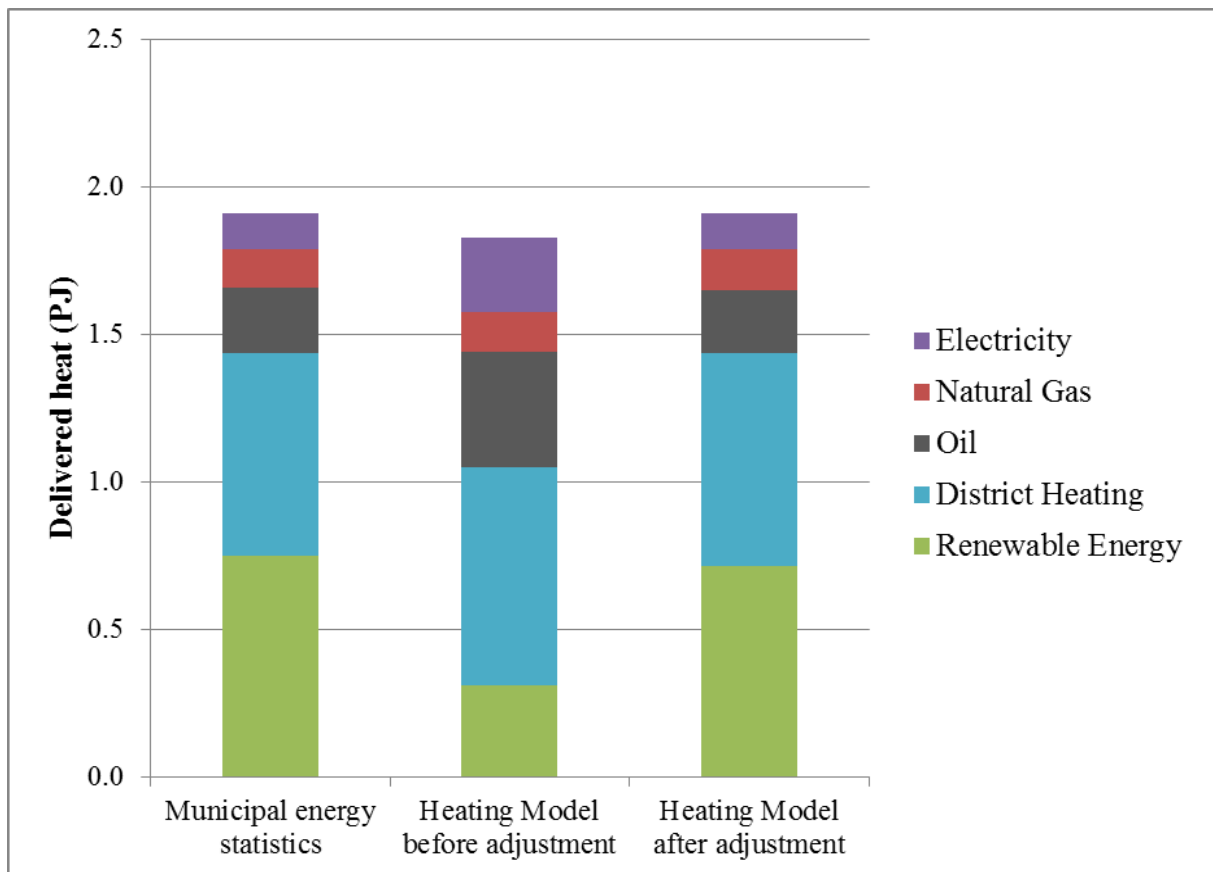


Figure 9. Calculated heat demand before adjustment with local conditions

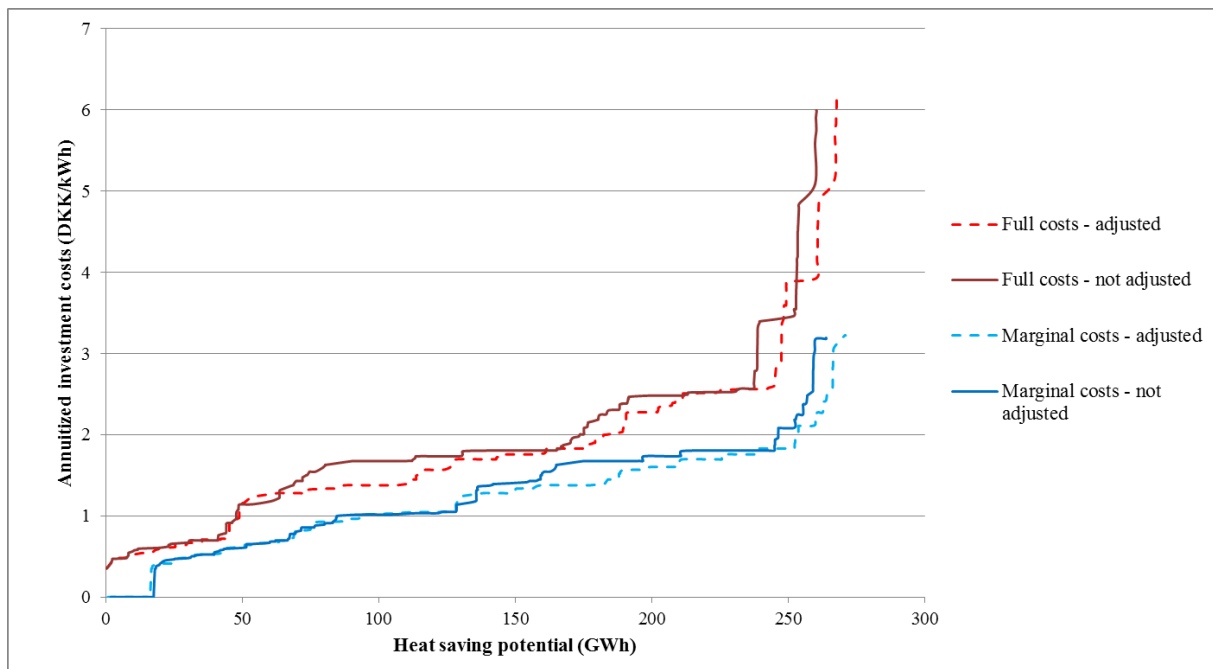


Figure 10. Potentials and annuitized investment costs of heat saving measures before and after adjustment with local conditions

Finding a location for a new wind farm

The aim of this analysis is to show how Ringkøbing-Skjern Energy Atlas can be utilised to find a suitable location for a wind farm in case that a wind farm is to be built within the municipality. The purpose is not to propose an exact method for site-selection but to illustrate the advantages of the energy atlas. The following data are utilised in the present analysis:

- Average wind speed within 200 x 200 m raster cells. Average wind speed determines the annual electricity production from a proposed wind farm and thus greatly influences economic profitability of the proposed project.
- Areas where wind turbines of up to 150 m would not be in conflict with the legislative boundary of at least 600 meters from residential buildings. These areas will shortly be called Allowed areas for wind turbines.
- Locations of existing wind turbines, medium and high voltage power transformers and state roads. Other data from the atlas, such as positions of municipal roads, railways, different technical facilities, natural areas, soil types, etc. could be incorporated in the analysis using the same principles.

The procedure is as follows:

1. Wind speed data and Allowed areas for wind turbines are projected on top of the base map, as can be seen in Figure 11.
2. Only Allowed areas for wind turbines areas are considered to be appropriate candidates for installation of wind turbines.
3. From the areas which are resulting from the previous step, only the areas where average wind speed at height of 100 m is greater than 8 m/s are considered to be appropriate candidates. The result is presented in Figure 12.
4. Existing wind turbines are projected on top of existing layer. To avoid positioning of new wind farm close to existing turbines, only areas distanced more than 1 km from existing wind turbines are selected from areas resulting from step 3. The result is presented in Figure 13.
5. 150 kV and 60 kV power transformers are projected on top of existing layer. To reduce the expenses for connecting the new wind farm with existing transmission and distribution infrastructure only areas distanced less than 1 km from existing power transformers are selected out of areas resulting from step 4. The resulting areas are suitable for installation of new wind farm. They are presented in Figure 14.
6. State roads are projected on top of areas resulting from step 4 and serial numbers are added, as presented in Figure 15. If larger areas would be preferable, locations 1, 2 and 3 are more suitable. If, for example, areas closer to state roads would be preferable, locations 4, 5, 6 and 7 are more suitable.

Data used in steps 1-4 are gathered from publicly available sources, so these steps could as well be performed from the national perspective. On the other hand, data used in step 5 are gathered from the transmission system operator and from local electricity distribution company. Thus, local perspective and locally gathered data enables step 5 to be performed.

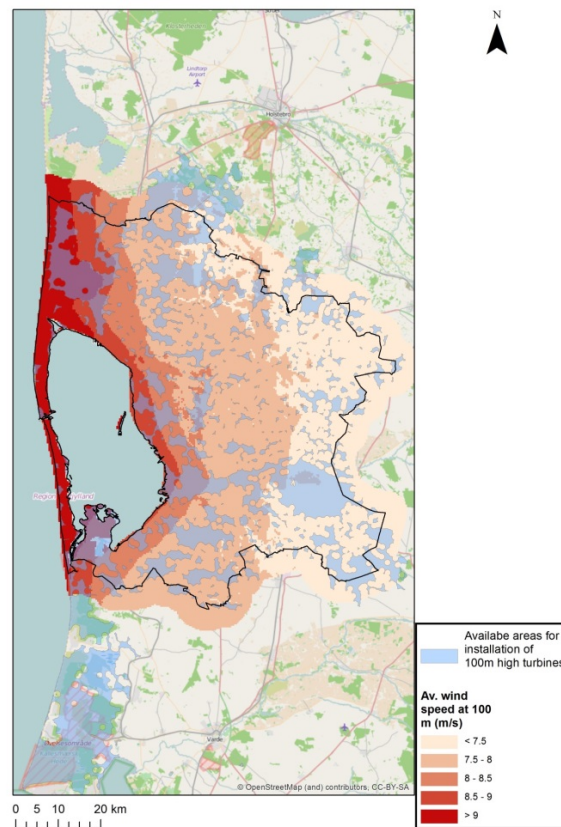


Figure 11. Wind speed and areas where installation of wind turbines is allowed

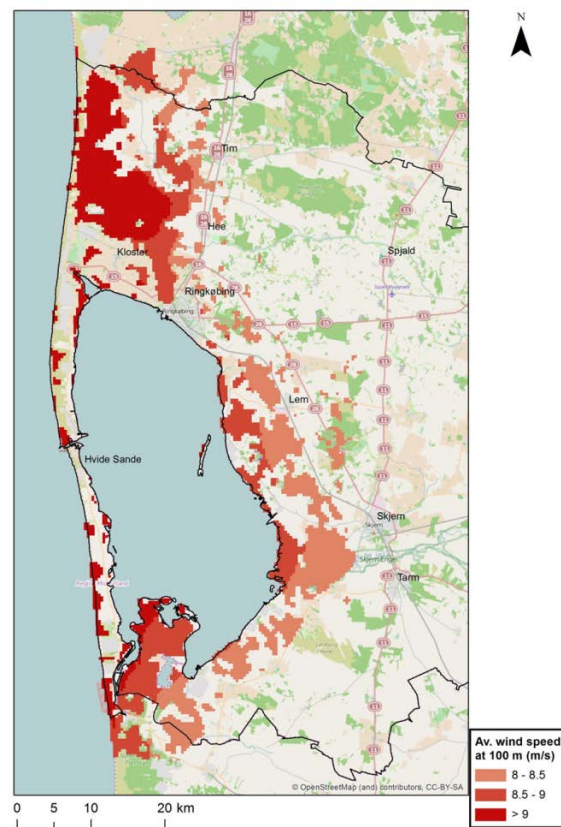


Figure 12. Allowed areas with average wind speed at 100 m greater than 8 m/s

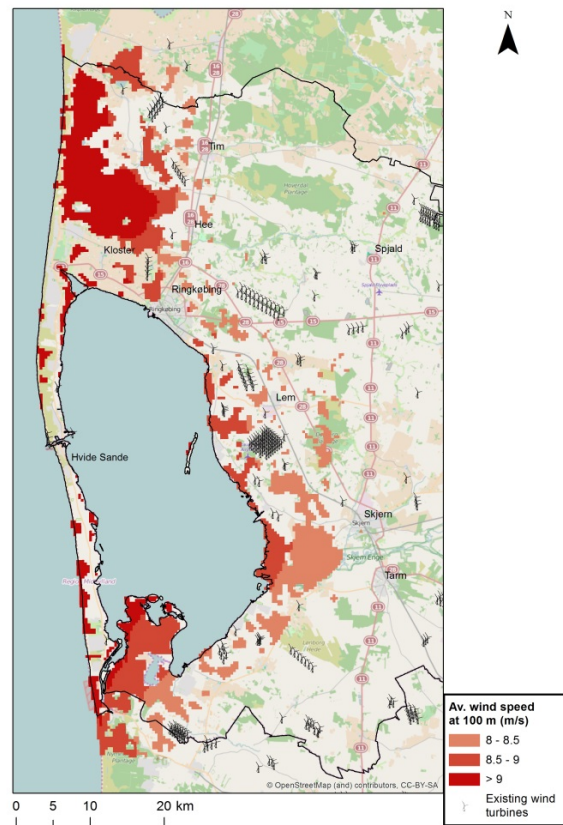


Figure 13. Resulting areas distanced more than 1 km from existing wind turbines

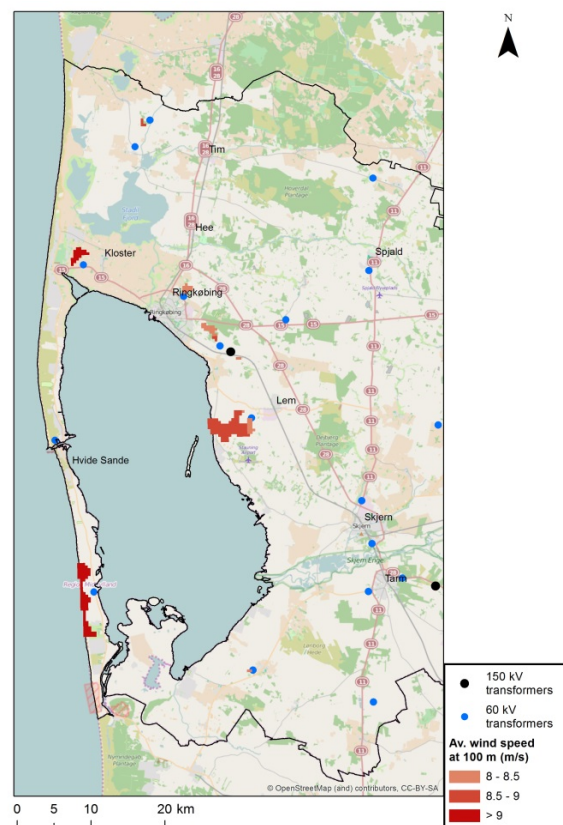


Figure 14. Resulting areas distanced less than 1 km from existing power transformers

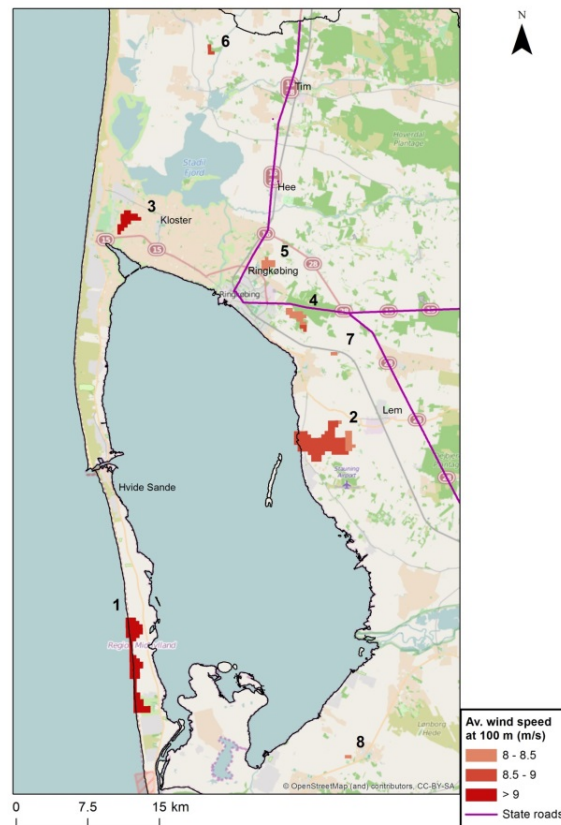


Figure 15. Resulting areas for installation of wind turbines and state roads

ROOM FOR IMPROVEMENT

Ringkøbing-Skjern Energy Atlas is a complete tool for energy planning and analysis - the data are collected, analysis tools are available through ArcGIS 10.1 software, it is documented and plan for future updates is established. Despite this, it can be improved or expanded in several instances:

- Positions of district heating distribution infrastructure and data about delivered heat to each building should be gathered for all district heating systems. Currently, consumption data is available for eight, while geographical data are available for five out of twelve district heating systems. However, for small district heating systems with a few hundred consumers, geographical data might not be available or are available in a form of paper maps only. On the other hand, heat delivered to each building is stated in the heating bills and thus are known for all district heating systems.
- Data about unoccupied buildings should be included in the atlas. Currently, in the calculation of heating demand, heat saving potentials and costs, all buildings are considered to be occupied. This change will increase the calculated heating demand in occupied buildings and consequently decrease the calculated costs of heat savings.
- Data about measured heat consumption should be added to the atlas. From 2011 all companies providing district heating, heating oil or natural gas to end users are required to report end-user consumption to BBR. However, the consumption of biomass is not reported.
- Waste heat resources should be added to the atlas. Low and medium-temperature heat sources can be significant in supplying inexpensive district heating.

- It should be decided which thematic data groups from Ringkøbing-Skjern Energy Atlas are necessary. Then, these data should be collected for other Danish municipalities and a Danish energy atlas should be created. GIS data with high level of details are publically available at [23-25], while data available in other municipalities, private and public companies are usually of the same quality as in Ringkøbing-Skjern. This would require a lot of time, resources and different types of expertise. Creation of such GIS energy atlas for countries other than Denmark will largely depend on data availability and confidentiality.

CONCLUSIONS

Ringkøbing-Skjern Energy Atlas is a GIS-based tool for energy planning and analysis. It is composed of a GIS database and tools built in ArcGIS 10.1 software. The database is characterized by high level of geographical and non-geographical details.

The data are collected from various sources – publically available databases, Ringkøbing-Skjern municipality and private and public companies. Thematically, the data belong to several groups: Energy resources, Transmission and distribution infrastructure, Supply and demand, Social data and Other energy data. The data are described in textual Description files: what do data represent, who provided it or where are they downloaded from and whether data are public or not.

In order to maintain its practical value, Ringkøbing-Skjern Energy Atlas needs to be regularly updated. The high level of details, wide range of thematic groups and different sources make the update process very challenging. Even more, some data are changing from year to year, while some are changing once in a decade. To facilitate the update process, Update list and Contact list are created. For all data in the atlas, Update list specifies preferred interval between updates, while Contact list contains contact details of persons which provided the data, along with their position and fields of expertise.

For users without major GIS experience, Ringkøbing-Skjern Energy Atlas is intended to be used as a data-container and a visualization tool. Advanced GIS users can query or edit the database, perform GIS analysis and spatially represent results. Three applications of the energy atlas have outlined in the present article: calculation of investment costs of district heating networks, calculation of potentials and costs of heat saving measures and finding location for new wind farm. In order to emphasize high level of geographical details and their influence, these applications have been compared with the equivalent procedures done from the national perspective. It is concluded that high level of details provides the possibility to perform more detailed analysis and include factors which are not available at the national level. Further analysis which can be performed by utilising Ringkøbing-Skejrn energy atlas include finding location for new biogas plant, estimation of biomass resources and finding the optimal position for future hydrogen charging stations.

Ringkøbing-Skejrn Energy Atlas can be further improved by adding the data about unoccupied buildings. In addition to that, the positions of district heating distribution infrastructure and data about delivered heat to each building should be gathered for all district heating systems. Industrial waste heat resources would represent valuable addition to the atlas, as well. Before adding new and more detailed data, Ringkøbing-Skjern Energy Atlas should be used in projects and regularly updated. This will reveal its practical value and might show some more areas for improvement.

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